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Controlled Power Cooperative Non Orthogonal Multiple Access Relay Networks

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ABSTRACT

Recent work related to cooperative communication and power allocation has attracted much attention among researchers. This paper compares orthogonal multiple access (OMA), non orthogonal multiple access (NOMA), and cooperative NOMA. NOMA takes the advantage of successive interference (SIC) for detection at the receiver. Strong(near) users are used as a relay for helping in transmission of weak (far) users or in other words cooperative communication is implemented. In this paper, near users are used as relays for far users. One far user and many near users scenarios are considered. The total transmission is divided into two stages namely: direct and the cooperative. The proposed work also give priority to certain users while maintaining the fairness in resource allocation. The simulated results from MATLAB verify the theoretical knowledge that cooperative communication outperforms non-cooperative communication for the outage probability, achievable rate, and transmit power. In this paper, closed form outage probability expressions are used.

***Index Terms*—**Achievable rate, capacity maximization, power allocation, relay, fairness maximization

I. INTRODUCTION

The relaying mechanism is an important method to improve the quality of wireless communication [1]. Due to channel fading, the relay can virtually extend the base station coverage, which can reduce the outage probability [2]. To achieve higher spectral and power efficiency, including network coverage while minimizing outage probability, cooperative relaying communication has emerged as a suitable approach [3]. So far, significant progress has been made regarding the relaying method to enhance fading channels through multipath propagation in wireless communication. Because of the nature of the relay technique in wireless communication, it has gained significant attention. Cell edge users are the most affected by impairments of signals [4].

This section examines related work compared to the proposed work regarding optimum power control to guarantee fairness maximization in the base station to relay wireless communication; optimum power allocation in a closed-form expression was proposed in [5]. As an effective means to mitigate the effects of channel fading, cooperative NOMA was proposed in [6] to improve resource allocation such as user's fair throughput. The work in [7] proposes a user group algorithm that maximizes the fairness of two-user multibeam satellite networks which are using NOMA. In [8], the maximum–minimum technique is proposed to improve priority for network resource allocation.

The authors in [9] proposed optimum fairness to maximize the user's achievable rate, and the closed-form optimal solution was derived. A cooperative diversity scheme to improve network coverage proportional fairness into a cooperation algorithm is proposed in [10]. In [11], dynamic power allocation with user mobility is proposed to achieve a gain of sum rate and rate fairness. The authors in [12] proposed an efficient power allocation method to maximize the minimum achievable vehicle rate to guarantee fairness.

II. RELATED WORK

A. Cooperative Diversity in Wireless Communication

The key aspect in developing cooperative multiple access transmission systems is that users with stronger signals act as a relay to cell edge users with weaker signals. Successive interference

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cancellation (SIC) is implemented at the receiver in the NOMA system. Using NOMA, the stronger user decodes the signal of the weaker user before it detects its signal, while the weaker user decodes its signal first before it detects the stronger signal. The transmission scheme exploits either the direct transmission phase or the cooperative transmission phase. Without the involvement of a cooperative technique, both signals from the weak and strong can be broadcasted by the base station (BS). In the event of cooperative communication, stronger users assist as a relay to forward the decoded information to the weak user by utilizing the SIC mechanism. By doing so, the weaker user's coverage reliability can be drastically enhanced.

B. Relay Protocol

Relaying protocol is the most fundamental enabler in wireless communication to extend cell edge coverage [13], the relay collaboration can be performed by using intermediary nodes to convey data to the destination (known as relays or helpers). Amplify and forward (AF) and decode and forward (DF) are two of the most popular cooperative networking strategies [14]. The most basic kind of collaboration is AF, in which the relay node amplifies and transfers the signal received from the source to the destination [2]. Relays, however, can use the DF approach to decode data before sending it to the target node.

Relay selection can be minimum or maximum depending on the desired output, as in Fig. 1 above. The authors in [15] discussed and developed the techniques to achieve ergodic capacity in the Rayleigh fading cases, and their work expanded to better signal-to-interference-plus-noise ratio (SINR) conditions to achieve maximum capacity in multiple input multiple output (MIMO) relay channels.

The work in [16] evaluated network coverage and performance analysis while examining how cache-aided interference can improve network performance. The authors in [17] investigated the system's throughput under relay-limited transmission modes.

In relay-to-relay scenarios, the study in [3] proposed comprehensive work on maximizing energy efficiency regarding sectorization coverage. The author evaluated an antenna selection scheme followed by a relay selection scheme [18]. The outage probability of the proposed scheme is plotted for different antenna configurations with variable SNR and distance, and the available relays with different antenna configurations are considered.

In [19], the authors outline an in-depth analysis of the outage performance analysis, including mathematical derivatives in a closed-form expression. This indicates that the system's outage performance is proportional to the spectral efficiency. Signal-to-interference-plus-noise ratio is a fundamental matrix in mobile wireless communication. The authors investigated devices to devise techniques to improve far user SINR [20]. Minimizing latency is the key aspect of 5th generation (5G) requirements [21]. The authors in [22] outline similar scenarios where the latency for high-reliability techniques has been investigated to improve multicast data in vehicle-to-everything communication.

When multiple relays using MIMO are deployed in a network with the aim of maximizing throughput, the system experiences interference among users. To overcome that, it is necessary to introduce algorithms in different topologies to minimize the outage probability

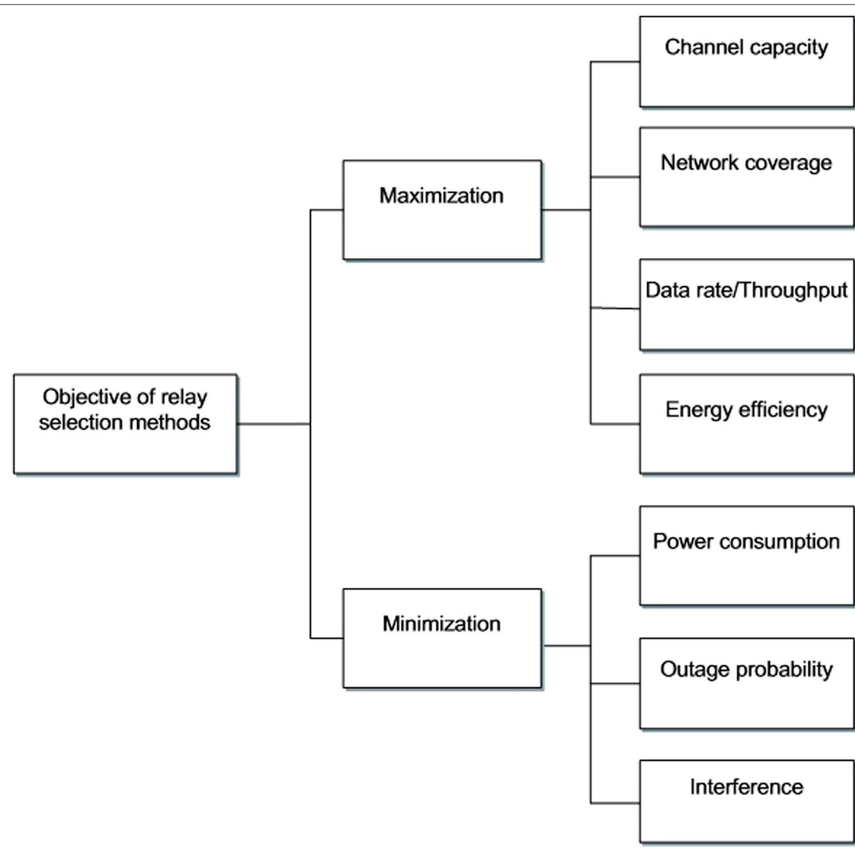

Fig. 1. Classification of objectives of relay selection method.

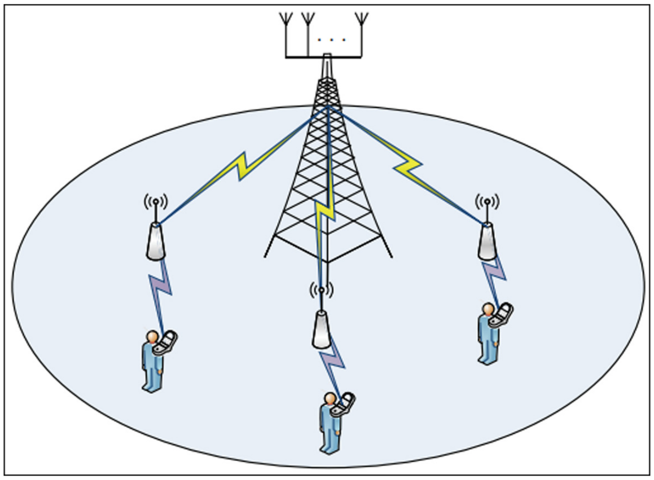

Fig. 2. Multiuser communication through multiple relays [23].

and interference while increasing spectral efficiency. Fig. 2 presents similar work to the proposed architecture, the only difference being the method and capacity to serve users. Based on NOMA principles, the proposed technique can be devoted to serving many users while maximizing fairness.

III. PROBLEM STATEMENT

Generally, the cellular system experienced exponential growth in application and data, and the increasing demand has pushed the evolution of 4G to the 5G network to support high data, reduced latency, better energy efficiency, reliable connectivity, and high data capacity [23]. In this research, a system fairness maximization approach to improve reliability in connectivity has been proposed. Users who are located far from the base station suffer considerably from providing reliability compared to near users, especially those users are in cell edges. NOMA multi-relay networks have been proposed to support such drawbacks. Additionally, to balance user fairness and obtain a fair recourse allocation mechanism, the network is optimized.

IV. PROPOSED WORK

Cooperative communication consists of the source node and users, unlike direct communication. The main idea behind cooperation is that stronger users act as a relay to boost the signal of the weaker users. In this research, NOMA-based cooperative multi-relay has been proposed to support far-user signals to deliver critical service. Fairness maximization in terms of power allocation techniques has been developed. Lastly, priority resource allocation has been developed to optimize system fairness regarding the power allocation algorithm.

Priority resource allocation has been proposed to serve users with priority service rather than the NOMA technique, where less power is given to a near user, and more power is allocated to a far user. In some instances, more resources can be directed to users who do not need to utilize them while users with high priority get fewer resources, which creates a huge challenge in wireless communication. The abbreviations and subscripts given in Table I.

TABLE I. NOTATIONS AND SUBSCRIPTS

h_n	Rayleigh's fading channel coefficient
x_1	Represents the joint signal of all the user
p_n	Power coefficients of the n^{th} user
MIMO	Multiple input multiple output (MIMO)
SINR	Signal-to-interference-plus-noise ratio

V. THE SYSTEM MODEL OF THE PROPOSED TECHNIQUES

A. Direct Transmission Stage

Fig. 3 shows cooperative communication where the base station BS communicates with multiple relays to serve multiple users cooperatively; for clarification of direct transmission, the base station communicates with the user without involvement of a cooperation. This research considers a downlink cooperative communication as well as priority resource allocation to improve user fairness. For direct communication, the base station transmits M user's messages using NOMA, where m_n represents the n^{th} user message and p_n represents the power allocation coefficient of n^{th} user [24] and the base station total message is $\sum_{n=1}^{M} p_n m_n$. Furthermore, h_n is Rayleigh's fading channel coefficient of the n^{th} user. Assume, for the sake of simplicity, that the users are arranged by the quality of their channels, i.e., $|h_1^d|^2 > |h_1^c|^2 \geq .... \geq |h_M^d|^2 \geq |h_{EU}^d|^2$ and power coefficients are $p_1^d < p_1^c \leq ... \leq p_M^d \leq p_{EU}^d$. The received message at the n^{th} user is

$$y_n = h_n^d \sum_{n=1}^{M} \left(\sqrt{p_n^d}\, x_n\right) + w_n^d \text{ with } p_1^d + p_2^d \ldots p_M^d + p_{EU}^d = 1 \quad (1)$$

w_n^d : denotes the Additive White Gaussian Noise (AWGN) for the n^{th} user, and the end user is denoted by EU and p_n power coefficients of the n^{th} user. If X_l represents the joint signal of all the users, then

$$x_l = x_1 + x_2 \ldots + x_M + x_{EU} \quad (2)$$

The successive detection is used for the detection of M^{th} user signal. The SINR received in M^{th} ordered users for the detection of n^{th} user message where $1 \leq n \leq M$ is

$$SINR_{M,n} = \frac{|h_n|^2 |p_n|^2}{\sum_{l=n+1}^{M} |h_M p_l|^2 + \sigma^2} \quad (3)$$

σ^2 denotes the variance.

B. In the Cooperative Stage

In the cooperative stage, near users are relays for far users. The near users first decode far-user signals and then cancel far users' signals using SIC to decode its signal. The use of the cooperative stage between the BS and relays (near users) improves the performance and reliability of far users. The near users utilize the information received from the direct transmission stage. The near users in the networks use one time slot for relaying the messages covering the interuser channels. The cooperative phase is therefore divided into $(M-1)$ time slots; this has been done to reduce interuser interference as each near user will use one time slot to relay the message they want to transmit. In this study, an example of M near users and

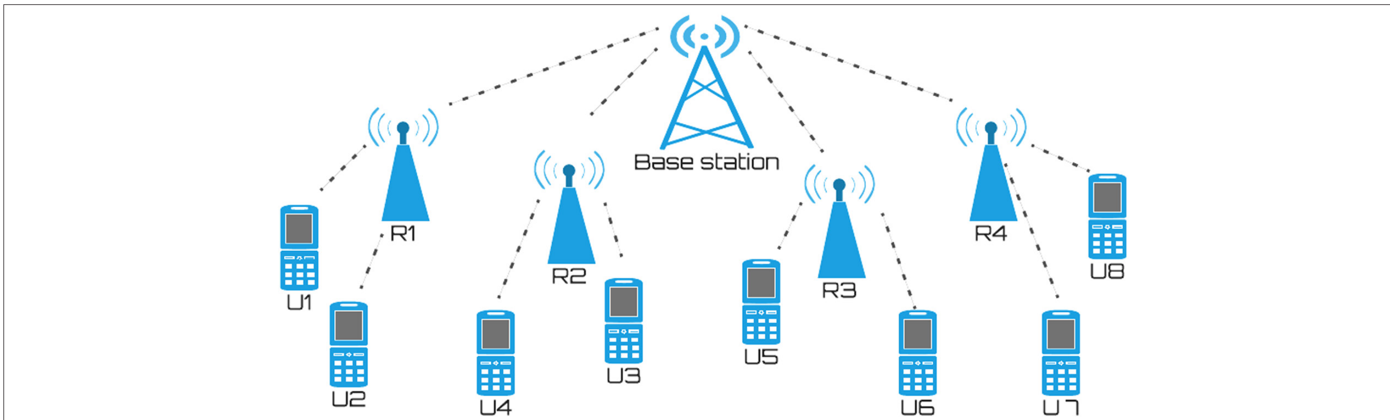

Fig. 3. Optimum power control for the base station to relay system model.

one far user is considered. At the beginning of this phase, near user 1 transmits a superimposed signal with the actual information signal to the far user. The messages received in the direct transmission phase are relayed by the user cooperative stage. At the beginning of the cooperative stage, near user 1 will broadcast combined data consisting of all the user's signals. The received signal at the far user receiver is

$$y^c_{FU,1} = p^c_1 h^c_1 x_{I-1} + w^c_1 \quad (4)$$

where p^c_1 is the power allocation for user 1 in cooperative phase.

The superimposed signal is denoted by

$$x_{I-1} = x_2 \ldots + x_M + x_{EU} \quad (5)$$

h^c_1 : Rayleigh coefficient between user 1 and far user.

w^c_1 : AWGN noise.

In a similar manner, the M^{th} user will transmit to the far user, and the received signal at the receiver of the far user is

$$y^c_{FU,M+1} = p^c_M h^c_M x_{I-M} + w^c_M \quad (6)$$

where p^c_M is the power allocation for the user M in the cooperative phase.

The superimposed signal is denoted by

$$x_{I-M} = x_2 \ldots + x_M + x_{EU} \quad (7)$$

h^c_M : Rayleigh coefficient between user 1 and far user.

w^c_M : AWGN noise.

VI. RESULTS AND SIMULATION

In this section, the performance of the proposed work is investigated using simulations in MATLAB v2022. Different parameters are used to compare the performance of far user performance for OMA (without NOMA), with NOMA with and without cooperation. From simulated results, the far user with cooperation has performed much better than the far user without cooperation and the far user without NOMA, which supports the theoretical assumption that cooperation outperforms non-cooperative and OMA, respectively.

As shown in Fig. 4, outage probability against SNR for three scenarios is compared. For cooperative NOMA, bit error rate decreases with an increase in SNR as compared to NOMA and OMA. Fig. 5 demonstrated the ability of NOMA over OMA in terms of capacity maximization.

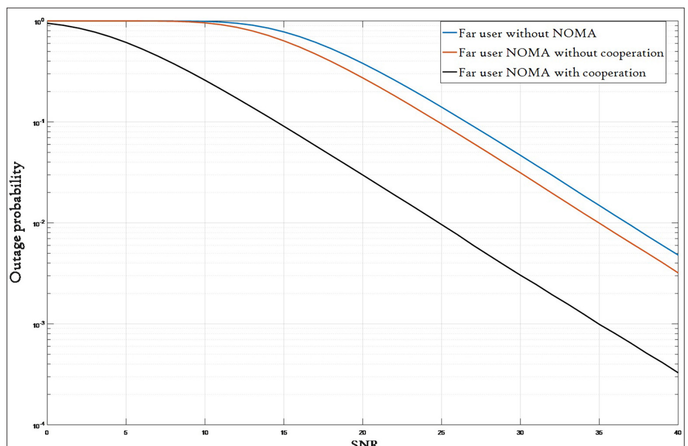

Fig. 4. Far user without NOMA, the far user with NOMA, and NOMA Cooperation.

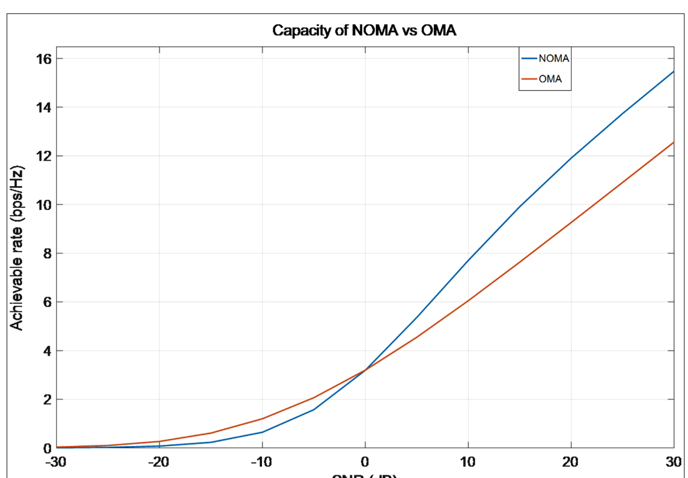

Fig. 5. Capacity of NOMA vs. OMA.

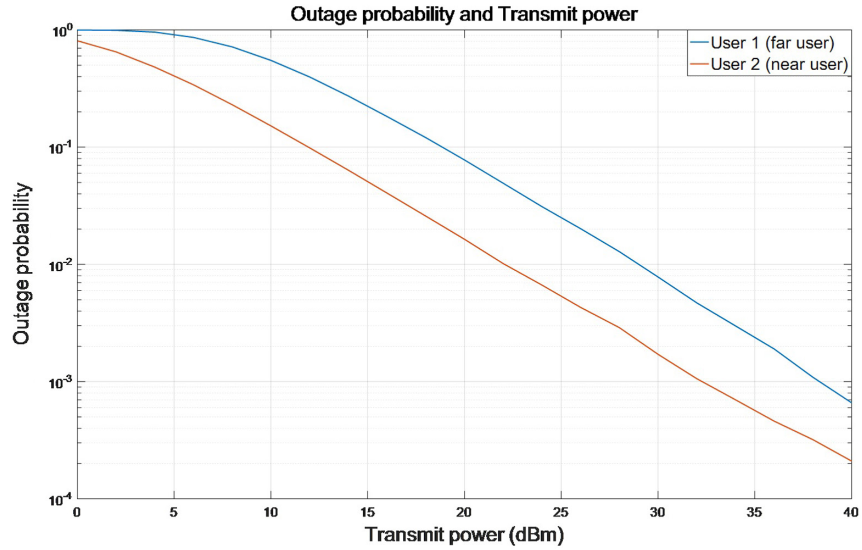

Fig. 6. Outage probability and transmit power NOMA vs. OMA.

For lower SNR values, OMA outperforms NOMA; however, as SNR increases the achievable rate possible in NOMA increases as compared to OMA.

Fig. 6 illustrates the outage probability of the near user and far user compared for different transmit powers. As transmit power increases, the outage probability of both users decreases. Outage probability is a measure of successful transmission, and the increase in transmission power decreases the chances of outage, leading to decrease in outage probability. The near user, being close to the BS, requires less power for transmission and has lesser outage probability.

VII. CONCLUSION

The work done in this study provides significant validation of the superior performance of cooperative communication to balance user satisfaction in terms of resource allocation to improve fairness maximization. In some cases, near users carry noncritical services while far users do; they need to maximize fairness to guarantee reliable connectivity in the mobile network. The work uses closed-form expressions for the outage probability for near users and far users. The work shows that the average achievable rate for NOMA outperforms OMA as SNR increases. Also, for higher transmission power, the outage probability of both types of users decreases: near and far. The work on NOMA is still significant; more research is still required to investigate the security aspect of NOMA and latency in the future.

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REFERNCES

1. N. Nomikos, T. Charalambous, D. Vouyioukas, R. Wichman, and G. K. Karagiannidis, "Integrating broadcasting and NOMA in full-Duplex buffer-aided opportunistic relay networks," *IEEE Trans. Veh. Technol.*, vol. 69, no. 8, pp. 9157–9162, 2020. [CrossRef]
2. J. Men, and J. Ge, "Non-orthogonal multiple access for multiple-antenna relaying networks," *IEEE Commun. Lett.*, vol. 19, no. 10, pp. 1686–1689, 2015. [CrossRef]
3. V. Balyan, "Cooperative relay to relay communication using NOMA for energy-efficient wireless communication," *Telecommun. Syst.*, vol. 77, no. 2, pp. 271–281, 2021. [CrossRef]
4. J. Awad, M. A. Imran, and R. Tafazolli, *Improving Fairness by Cooperative Communications and Selection of Critical Users*, 2011, pp. 184–188. [CrossRef]
5. S. Wang, S. Cao, and R. Ruby, "Optimal power allocation in NOMA-based two-path successive AF relay systems," *J. Wireless Com. Network.*, vol. 2018, no. 1, p. 273, 2018. [CrossRef]
6. F. Salehi, N. Neda, M. Majidi, and H. Ahmadi, "Cooperative NOMA-based user pairing for URLLC : A max – Min fairness approach," *IEEE Systems J.*, vol. 16, no. 3, pp. 3833–3843, 2021. [CrossRef]
7. J. Biyoghe, and V. Balyan, "Users' grouping algorithm for fairness improvement of NOMA-based multi-beams satellite networks intended for 5G," *IET Commun.*, vol. 17, no. 15, pp. 1780–1790, 2023. [CrossRef]
8. M. Koppen, K. Ohnishi, and M. Tsuru, "Maxmin fairness under priority for network resource allocation tasks," 2014 IEEE 38th Int. Comput. Softw. Appl. Conf. Workshops, Vasteras, Sweden, 2014, 2014, pp. 49–54. [CrossRef]
9. T. Qi, W. Feng, Y. Chen, and Y. Wang, "Optimum fairness for non-orthogonal multiple access," 2018 IEEE/CIC Int. Conf. Commun. China (ICCC), Beijing, China, 2018, 2018, pp. 116–120. [CrossRef]
10. E. Liu, and S. Member, *Relay-Assisted Transmission with Fairness Constraint for Cellular Networks HIS Paper*, Vol. 11, no. 2, 2012, pp. 230–239.
11. B. Narottama, and S. Y. Shin, "Dynamic power allocation for non-orthogonal multiple access with user mobility," 2019 IEEE 10th Annu. Inf. Technol., Electron. Mobile Commun. Conf. (IEMCON), Vancouver, BC, Canada, 2019, pp. 442–446. [CrossRef]
12. Z. Wang, J. Hu, G. Liu, and Z. Ma, "Optimal power allocations for relay-assisted NOMA-based 5G V2X broadcast / multicast communications," 2018 IEEE/CIC Int. Conf. Commun. China, no. Iccc, Vol. 2018, 2018, pp. 688–693. [CrossRef]
13. X. Liu, and X. Wang, "Outage probability and capacity analysis of the collaborative NOMA assisted relaying system in 5G," in 2016 IEEE/CIC Int. Conf. Commu. China, ICCC 2016, Vol. 2016, 2016. [CrossRef]
14. J. -B. Kim, and I. -H. Lee, "Non-orthogonal multiple access in coordinated direct and relay transmission," *IEEE Commun. Lett.*, vol. 19, no. 11, pp. 2037–2040, Nov. 2015. [CrossRef]
15. B. Wang, S. Member, A. Host-Madsen, A. Høst-madsen, and S. Member, "On the capacity of MIMO relay channels," *IEEE Trans. Inform. Theory*, vol. 51, no. 1, pp. 29–43, 2005. [CrossRef]

16. A. Multicasting, “Coverage performance analysis of wireless caching networks with non-orthogonal multiple,” *IEEE Access*, vol. 7, pp. 164009–164020, 2019.
17. X. Wang, M. Jia, I. W. Ho, Q. Guo, and F. C. M. Lau, “Exploiting full-Duplex two-way relay cooperative non-orthogonal multiple access,” *IEEE Trans. Commun.*, vol. 67, no. 4, pp. 2716–2729, 2019. [CrossRef]
18. V. Balyan, “Evaluation of antenna and relay scheme for cooperative non-orthogonal multiple access,” *IET Netw.*, 2023. [CrossRef]
19. M. Antonio, B. De Melo, and D. Benevides, *An Efficient Relay – Destination Selection Scheme for Multiuser Multirelay Downlink Cooperative Networks*, Vol. 61, no. 5, 2012, pp. 2354–2360.
20. Y. B. Song, H. S. Kang, and D. K. Kim, “5G cellular Systems with D2D assisted NOMA Relay,” in 2016 URSI Asia-Pacific Radio Sci. Conf. (URSI AP-RASC), Vol. 2016, 2016, pp. 1–3.
21. Y. Hu, M. C. Gursoy, and A. Schmeink, “Relaying-Enabled Ultra-Reliable Low-Latency Communications in 5G,” pp. 62–68, 2018.
22. G. Liu, Z. Wang, J. Hu, Z. Ding, and P. Fan, “Cooperative NOMA broadcasti ng/multicasting for low-latency and high-reliability 5G cellular V2X communications,” *IEEE Internet Things J.*, vol. 6, no. 5, pp. 7828–7838, 2019. [CrossRef]
23. N. Madhusudhanan, R. Venkateswari, and A. Abraham, “Cooperative communication for 5G networks : A green communication based survey,” *Internati. J. Inform. Scien. Compu.*, vol. 4, pp. 65–78, 2017. [CrossRef]
24. Z. Ding, M. Peng, and H. V. Poor, “Cooperative non-orthogonal multiple access in 5G systems,” *IEEE Commun. Lett.*, vol. 19, no. 8, 1462–1465, 2015. [CrossRef]

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